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CAN DUCT-TAPE TAKE THE HEAT?©

Max Sherman
Iain Walker
Energy Performance of Buildings Group
Lawrence Berkeley National Laboratory
University of California

Duct leakage has been identified as a major source of energy loss in residential buildings. Most duct leakage occurs at the connections to registers, plenums or branches in the duct system. At each of these connections a method of sealing the duct system is required. Typical sealing methods include tapes or mastics applied around the joints in the system. Field examinations of duct systems have typically shown that these seals tend to fail over extended periods of time. Three test methods were used to test the longevity of duct sealants: simple heating, cycling heat and pressure and cyclic aging. The most advanced method was the "aging" test, developed to evaluate the longevity of duct sealants by alternatively blowing hot (75°C, 170°F) and cold (-12°C, 10°F) air through test sections, with the apparatus cycling between hot and cold air quickly. The temperatures and cycle length were chosen to accelerate the aging process of the duct seals. The aging apparatus was able to test eight samples at a time, with the test samples constructed from standard duct fittings. The results of these tests were used to evaluate different sealants relative to each other, so that recommendations regarding duct sealants may be developed. Typical duct tape (i.e. fabric backed tapes with rubber adhesives) was found to fail more rapidly than other duct sealants.

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As anyone who has crawled around attics looking at ductwork knows, the sight of failed duct tape is an all too frequent sight. Popular culture abounds with uses for duct tape in duct tape calendars, 101 uses for duct tape, duct tape books, etc. Unfortunately, it appears that duct tape should not actually be used to seal ducts.

All current air distribution systems require some sort of sealant between duct sections, at branches and at plenum and register connections. Without these seals, duct systems would be extremely leaky and hence inefficient. While some duct sealant technologies are rated (e.g. by Underwriters Laboratory) on their manufactured properties, none of these ratings addresses the in-service lifetime. A key piece of the sealant selection puzzle would be answered if relative ratings for sealant longevity existed. To examine this question, LBNL has used laboratory methods for testing duct sealants.

The conclusion we can draw so far is that one can use ABD (Anything But Duct-tape), where we define "duct tape" in its most familiar incarnation. We can roughly define classes of duct sealing we have tested in the following way:

- **"Duct-Tape"** is typically cloth-backed and has a rubber-based adhesive. It comes in wide variety of grades with different tensile strengths. The classic duct tape is silver/gray, but is actually available in many colors. .
- **"Packing Tape"** has a thin typically clear polyester backing and an acrylic adhesive. Its tensile strength is usually low unless it has fiber reinforcing. Packing tape is often used on factory-assembled duct systems.
- **"Foil Tape"** has metal foil backing and like packing tape has an acrylic adhesive. Foil tapes are often used on rigid duct systems (e.g. duct board)..
- **"Butyl Tape"** typically has foil backing as well, but uses a thick (15-50mm) butyl adhesive to allow it to conform to more irregular shapes.
- **"Mastic"** is wet application, gooey, adhesive that fills gaps and dries to a soft solid. Mastics may also be used together with reinforcing fibers.
- **"Aerosol Sealant"** is a sticky vinyl polymer that is applied to the leaks internally, by pumping aerosolized sealant through the duct system, which then spans the leak and dries.

Why Do We Care About Duct Sealing?

Air distribution systems are responsible for delivering conditioned air to the vast majority of houses in the U.S. The efficiency of delivery can vary by a factor of two from one duct system to another and result in can wasting a lot of energy and money. There are many factors that affect the efficiency of duct systems, but three most important are *location, location, location.*

The best location for the duct system (return, supply, and air handler) is inside the conditioned space. In-space duct efficiencies can easily approach 100%. The worst location for the duct system is usually in the attic, especially when air conditioning is important. Attic duct efficiencies during peak periods can drop to 50%, wasting half the system energy and capacity. Intermediate values are found for ducts that pass through buffer zones (e.g. unconditioned basements, exterior wall cavities, inter-floor spaces etc.) For a given duct system location duct leakage is the most important variable in determining duct efficiency.

Duct systems in the U.S. are normally field designed and assembled. There are many joints, often of dissimilar materials. The mechanical fastening of the duct system components together does not usually provide an air seal. High pressure drops in the vicinity of the air handler and associated plenum, make even small holes result in a large leakage flow. Thus, if there were no explicit sealing, more air could flow out the leaks in a typical duct system than the registers. Standard practice accordingly calls for all joints in the duct system to be air sealed in addition to mechanically fastened.

Taping is the dominant sealing method in current practice. Mastics are disliked by field crews because they tend to be messier. Foil tapes are used on duct board, but duct tape is the most popular field solution on flex duct or metal. Each sealant choice has different advantages or disadvantages, but a reasonably careful job of application, can produce a good initial seal for any of them.

While any sealant method can produce a good initial seal, it is not clear that all last equally well. Houses are said to be designed to last 30 years. Flex duct systems are often rated at 15 year life. Ideally, duct seals should last at least as long as the rest of the duct system, but are often observed to fail in a few years. Poor installation of sealants (e.g., on dusty surfaces prevalent during construction) can be a contributing factor (and will not be addressed in this report), but it appears that physical properties of some of the sealants themselves may result in poor seal longevity.

Aren't There Standards for Duct Sealants?

There are existing standards that relate to duct tape and other duct sealants. Underwriters Laboratory has several, but the most relevant one is the UL 181 series, which deals with air ducts. The main standard deals mostly with factory assembly issues, but UL 181A and UL 181B, both of which are relatively new, deal with field assembled rigid and flexible duct systems respectively. The most recent addition to the UL 181 family of standards is UL 181B- FX which is for (adhesive) tapes on flex duct. The most common duct system in new construction is field-assembled flexible ductwork, therefore UL 181B (including UL 181 B-FX) is the most relevant to our interests. Some codes are now requiring that UL 181 be met for new duct systems.

While the UL standards do not directly address longevity issues they are relevant to the choice of sealants for various uses. Table 1 indicates the tests that are included in UL 181A & B:

Table 1 UL 181 tests

Test Name	UL 181 A	UL 181 B	Notes
Tensile Strength Test	x	x	Tapes only
Tensile Joint Strength Test	x		Mastics only
Peel Adhesion Test at 180 Degree Angle	x	x	Tapes only
Shear Adhesion Test	x	x	
Adhesion Test	x		Mastics only
Peel Adhesion Test at 20 Degree Angle	x		Tapes only
Freeze/Thaw Test (in container)	x	x	Mastics only
Surface Burning Characteristics Test	x	x	
Mold Growth and/or Humidity Test	x	x	
Temperature/Pressure Cycling Test	x		
Temperature Test		x	
Burning Test	x		

Although UL tests are primarily for safety one might assume from the nature of these tests that would serve the purpose of determining which tapes would perform their primary job of sealing leaks. Some interesting limitations and differences for the UL tests include the following:

- Fabric duct tapes have a clamp on the joint (not common in field).
- Shear Adhesion test (several parts) has one temp at 23 °C and another at 66 °C. The only attempt at aging has no load for 60 days at 66 °C and then a test at 23 °C for 24 hours, in which the tape may come off by 1/8 inch/24 hours (at that rate it can come off over a few days and still pass).
- The High Temperature Test (60 days at 100 °C) is evaluated by visual inspection only, no adhesion test
- The Mastic Freeze/Thaw Test is done (unless the container says to prevent freezing) with the mastic in its container, not applied to a surface.
- The surfaces to which the tape/mastic are applied are all clean (not common in the field), this is a limitation that our tests also have .

- That there is no cycling of temperature or pressure for adhesion tests in 181B (181A has pressure cycling at 74,32,-18 °C, but no temperature cycling)
- No cold conditions, and no condensation and/or freeze test at all (the Freeze/Thaw test is for mastic in their containers, not applied to a duct system)
- That the Shear Adhesion test is only for 24 hours of load

As of now there is no test applicable to the aerosol sealing method. As currently configured, thick, soft adhesives such as the butyl tapes cannot meet the tests.

Some tapes are rated to UL 723 for fire safety, but do not have a UL 181 rating. Most of the tapes that do have a UL 181B-FX rating for use on flex-duct are duct tapes. Duct tapes are the ones observed in the field to have poor sealing performance.

*So How **Can** We Determine Sealant Performance?*

UL 181 tests appear to do a quite good job at testing for safety, tensile strength and initial adhesion. They may not do a good job of rating sealants for the ability to seal typical duct leaks and, most importantly, to stay sealed when subjected to the environmental conditions normally experienced by ductwork.

To evaluate sealant longevity, we decided to develop some testing methods in which we would stress a standardized joint configuration with different environmental conditions and see how well the sealant held up. By using a standardized test configuration and application protocol, our test would focus on sealants ability to withstand the environmental conditions but we would not address installation issues. We came up with three different test procedures to use: baking; cycling, and aging.

Baking

The baking test is the simplest test of all. In it we place a standardized duct joint, sealed according to manufacturers instructions into an oven set to a temperature typical of a hot attic, typically in the range of 140F to 180F. Temperatures are kept below 200F because some of the tapes have that temperature rating. The standard joint (i.e. the test section) we used was round, right angle, metal-to-metal joint typical of a duct to plenum connection. The test section has as low a mass as possible to accommodate a method to test its leakage area. The setup tests the sealant applied to a standard 4” sheet metal collar in a plenum. This leak geometry was selected because it represents common practice. The two inch orifice is fitted just after the entry because it was found that a flow straightener was necessary for repeatable results from the measurement orifice

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Figure 1: Leakage Flow Measurement Setup

The test section has three quick connect fittings which are fitted with appropriate orifices when the leakage is to be measured. (See Figure 1.) It is expected that initially the leaks will be nearly 100% sealed and a method of measuring very low leakage is required. Several orifices (from ¼ to 1 ¼ inch) have been calibrated to measure leakage from 0.1 to 25 cfm @ 25Pa pressure difference across the walls of the duct.

The sample joints are all tested for leakage before any seal is applied. The test sections that have been built have pre-sealed leakage within a relatively narrow range of around 10 cfm @ 25 Pa. After sealing all the joints have close to the same small amount of leakage, typically less than 0.5 cfm @ 25Pa.

After being placed in the oven, the test samples were visually inspected at various intervals to note any failures. The leakage of each sample was also be re-measured to get a quantitative estimate of the failure rate with time. To date the only samples that have shown degradation from baking are those with rubber based adhesives (i.e. duct tapes). Visual inspections indicate that at the elevated temperatures of the oven, rubber based adhesives change their properties and have a tendency to delaminate.

The test sections for baking are the same one used for the aging test (described below). This was done so that the same leakage measurement rig could be used for both tests and so that the capability would exist to pre-bake samples before subjecting them to the aging test.

Cycling

The baking test subjects the test sample only to the stress of heat. In the cycling test, we subject a test sample to cyclic temperature and/or pressure stresses by blowing heated or room temperature air through the sample at various pressures.

This cycling apparatus was funded three years ago by EPA to measure the longevity of the aerosol sealant technique developed at LBNL under accelerated conditions. This testing involved open cycle, heated air - testing of a few aerosol-sealed leaks with about a 20 minute cycle time at about 200 Pa of pressure. We have kept the system running and have been monitoring the progress continuously. The system has been taking data for over 18 months and the measured leakage is displayed in Figure 2. The apparatus consists of eight test sections in parallel so that a range of test sections can be evaluated simultaneously. Before applying the sealant, the leaks were approximately 100 cfm (at 25 Pa) combined. As shown in the figure, after sealing they were down to approximately 7 cfm (at 25 Pa).

The data displays very little change over the measurement period. Not only has there been no failure, but a slight downward drift may be seen in the data compared to the horizontal line. If true, this trend would indicate that the seal was getting tighter with time. This might be caused by dust build-up improving the seal. The trend is sufficiently small, however, that it is more likely statistical or experimental bias. This cycling apparatus will be used in the near future for sealants other than the aerosol.

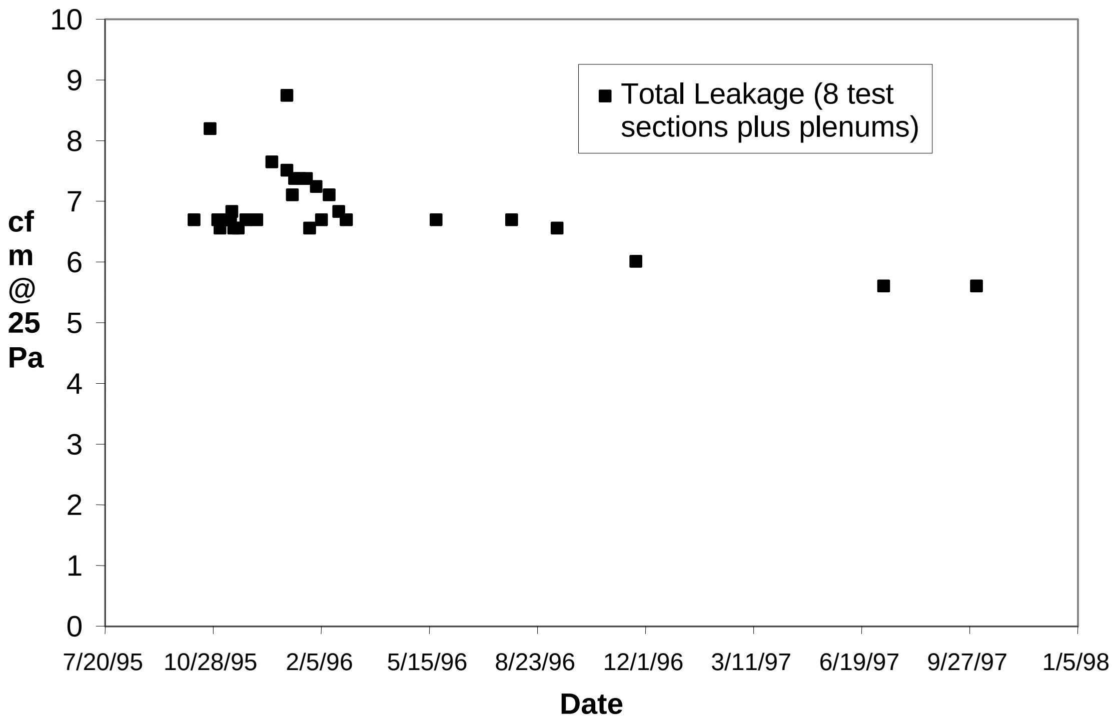

Figure 2 Aerosol Longevity test results from EPA test apparatus.

Aging

The twenty minute cycle time of the cycling test was limited by the need to warm up and cool down the test sample. Also the cycling apparatus could not subject the test sample to the cold temperatures that might be expected either in the winter or in air conditioning supply ducts. The aging test was designed to be able to overcome these limitations and provide accelerated longevity testing.

The aging apparatus was built last year using funding from the California Institute for Energy Efficiency. The design of the aging apparatus is intended to overcome many of the limitations imposed by the cycling and ultimately to perhaps become a standardized way of testing the longevity of duct sealant systems using accelerated methods.. The specific design objectives include the following:

- Combined thermal and pressure cycling in a typical pressure range.
- Rapid cycle times: 6 minute target to speed up the aging process.
- Maximum duct surface temperature should be as hot as the hottest attic, but under 200F
- Minimum duct surface temperature should be cold enough to form condensation and perhaps frost.
- A standardized leak and process should be used so that only the sealant is being tested.
- Multiple sealant materials evaluated simultaneously:
- Automated data taking and leak monitoring.

Towards these ends we have designed a test system which has a source of hot air (the hot deck) and a source of cold air (the cold deck). (See Figure 3). A selector valve, directs air from either the hot deck or the cold deck to flow through each test section. Air exiting the test section is recirculated to reduce the heating and cooling load. Half of the test sections have hot air while the other half have cold air flowing through them. When the selector valve changes position, the sections that had hot air blown through them now have cold air and the previously cold air sections get hot air. This alternating of hot and cold air provides the thermal cycling. In addition, the pressures changed in the system with each cycle as the previously hot section cooled, the pressure decreased form about 200 Pa to 100 Pa (these pressure differences are all relative to the room - i.e. across the seals). Similarly, the previously cold section pressure increased by a similar magnitude. An orifice downstream of the fan was used to control the pressure at the leak site and was also used to monitor the system air flow. The hot and cold decks were designed to have high (thermal) mass to make the load on the system steadier.

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Figure 3 Aging Test Apparatus

The mass in the hot air deck consisted of multiple pieces of sheet metal and weighs about 150 lb. (70 kg). The flow resistance of this mass has been calibrated so that it can be used as a flow meter. A location for air to flow into the system was provided to allow outflow at the leaks, this make-up air was brought into the system at the low pressure side of the fan. The makeup air to the hot deck was fitted with a calibrated anemometer, which measured the total leakage flow of the hot deck and the four sections that are currently selected to it. It measured the other 4 test sections when the selector was in the other state. This total leakage was continuously monitored so that we could detect catastrophic seal failure and record the failure time. Periodically (every few days), the test sections had their leakage measured individually, using an orifice flowmeter. This measurement was in addition to the four sample total measured by the orifice mounted in the system.

The decks are made of two kinds of insulation. The inner layer is standard one inch thick fiberglass duct board. The outer layer is two inch thick cyano-acrlyic board. (Cyano-acrlyic board has a moderate upper temperature limit, thus the two layer approach.) Combined they have an insulation value of about R-19.

The test sections used in the aging apparatus are identical to those in the baking apparatus so that a baked sample can also be placed in the aging apparatus. Each test section can connect to either a hot or cold deck through a selector. Figure 4 shows the geometry of a test section as installed.

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Figure 4 Test Connection for Duct Seal Longevity Testing

Figure 5 shows the temperature cycling for one of the current test samples. The hot plenum was operating at 170°F (75°C) and the cold plenum operated at 10°F (-12°C). The test sample surface temperatures had a maximum of about 140°F (60°C) and a minimum of 32°F (0°C). These surface temperatures were not as extreme as the plenum temperatures, but still provide a reasonable stress for the sealants. The cold plenum temperatures greater than 0°C were measured during the defrost cycle for the cooling coil.

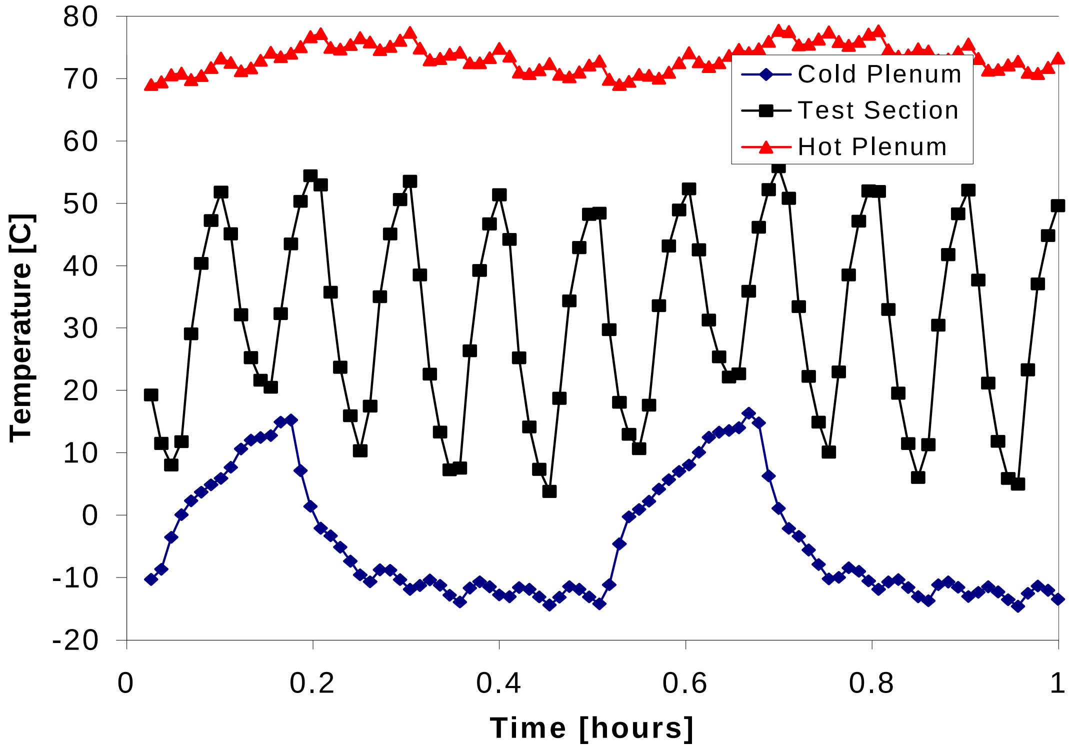


Figure 5. Temperature cycling in aging apparatus

The aging apparatus is the best one we have for doing accelerated testing and we have been able test a couple of dozen samples since it has been operational.

What Should We Test?

In selecting the samples to be tested in our apparatus we wish to use those tapes and sealants which are either commonly used or are being considered for use in various programs. One exception to this criterion is that we do not plan to test any tape that has a maximum temperature rating below 140 °F (60 °C). Not only would we expect it to fail quickly in our accelerated testing because of its higher temperatures, but we do not believe that any duct tape with such a poor temperature rating should be used, since either hot attics or gas heating could easily expose ducts to such temperatures.

In preparation for testing we have kept in touch with the major tape and sealant manufacturers to make sure we know the range of products available and to see which ones have been certified by UL. We have obtained many samples of “Duct Tape” from several companies. There is a wide range of products available that claim to suitable for duct sealing, but there is often little in their specs or product literature to differentiate them.

While there is general agreement that there are several grades of “Duct Tape” it is not clear what that means. For example one major manufacturer lists 16 different cloth duct tapes (not including color variation) and 8 metalized tapes. Some of these tapes have their product codes printed on the tape, some on the hubs, and some do not have any product number on them. All the cloth tapes meet UL 723 (Test for Surface Burning characteristics of Building Materials) but only some of the metalized ones do. Some are listed as “Code Approved” (BOCA, HUD) but a tape that has nearly the same specs does not indicate that it

Catalogues call the different tape grades Economy, Utility, General Purpose, Contractors, Industrial, Professional, Premium and even Nuclear! They are all listed as being used on HVAC ducts. Several companies have just come out with a UL 181B-FX tape, generally these are not even listed in the product catalogs yet. While we have not investigated mastics as much, there seems to be fewer grades. Few mastics are currently UL 181B approved although many are UL 181 A. It is expected that this situation will change in the future.

Figure 6 shows pictures of four of the first set of samples that went on the aging apparatus:

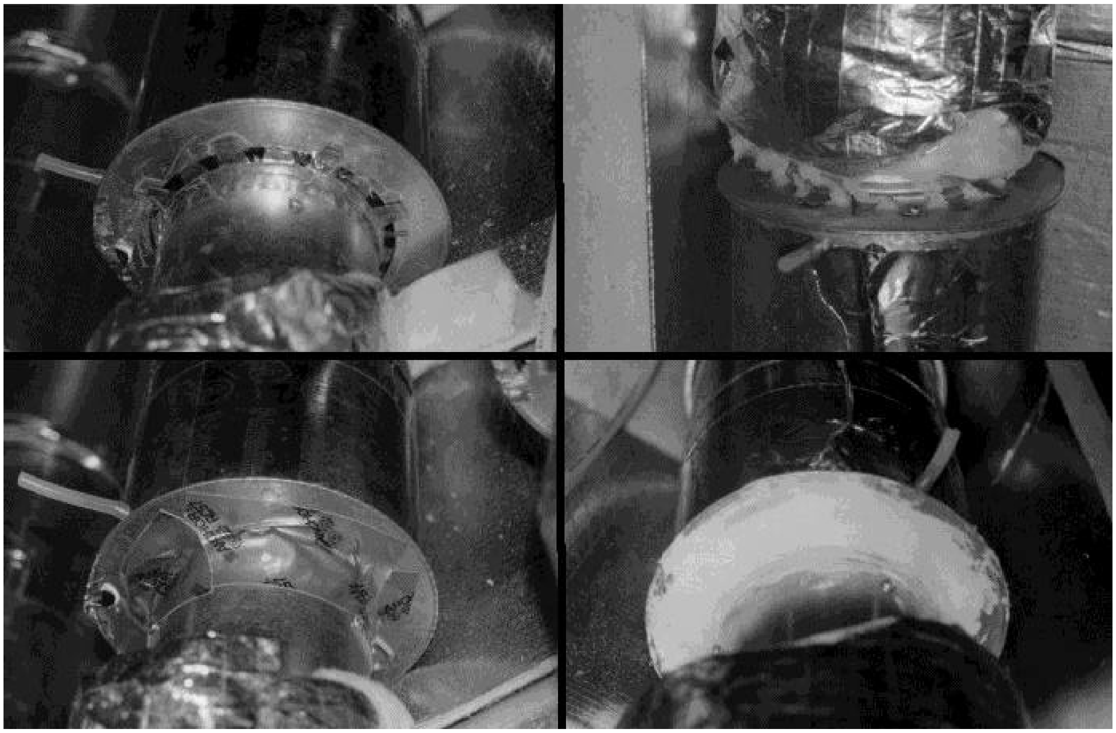


Figure 6. Four longevity samples. Clockwise from top left: packing tape, aerosol sealant, mastic and 181B-FX duct tape.

Let The Testing Begin

When we began the aging experiments we fully expected it to take weeks to begin to see degradation in performance. We were quite surprised to find that some of the sealants were failing in a matter of days. Most of the failure modes to date have been what might be termed catastrophic rather than gradual. This is in some ways fortunate because determining an exact numerical failure criterion is somewhat arbitrary. Nevertheless, we have used the guideline that a seal has failed when it lets more than 10% of unsealed flow pass through.

Figures 7 shows the change of leakage for some early test samples with time in the aging apparatus. The initial high leakage number (about 10 cfm @ 25 Pa) is the leakage of the test section before the sealant was applied. All of these cloth backed tapes showed visible signs of failure within about 3 days of the start of the test. Visible signs include: shrinkage of cloth backing, wrinkling and delamination of cloth from adhesive. The measured leakage for the cloth tapes showed that samples had about 10% to 20% of the unsealed leakage at the end of the period. The "Premium Grade" tape failed completely (it fell off the test section), but the other tapes had just started to delaminate at this time. This complete failure was due to separation of the cloth backing from the glue due to the thermal effects and pressure cycling. A second sample of the Premium Grade tape was tested to see if this was a repeatable failure; it lasted about 7 days before complete failure (note that this second sample is not shown in the figures). The metal backed tapes, the aerosol and the mastic show no visible of measurable signs of degradation after these two weeks of testing.

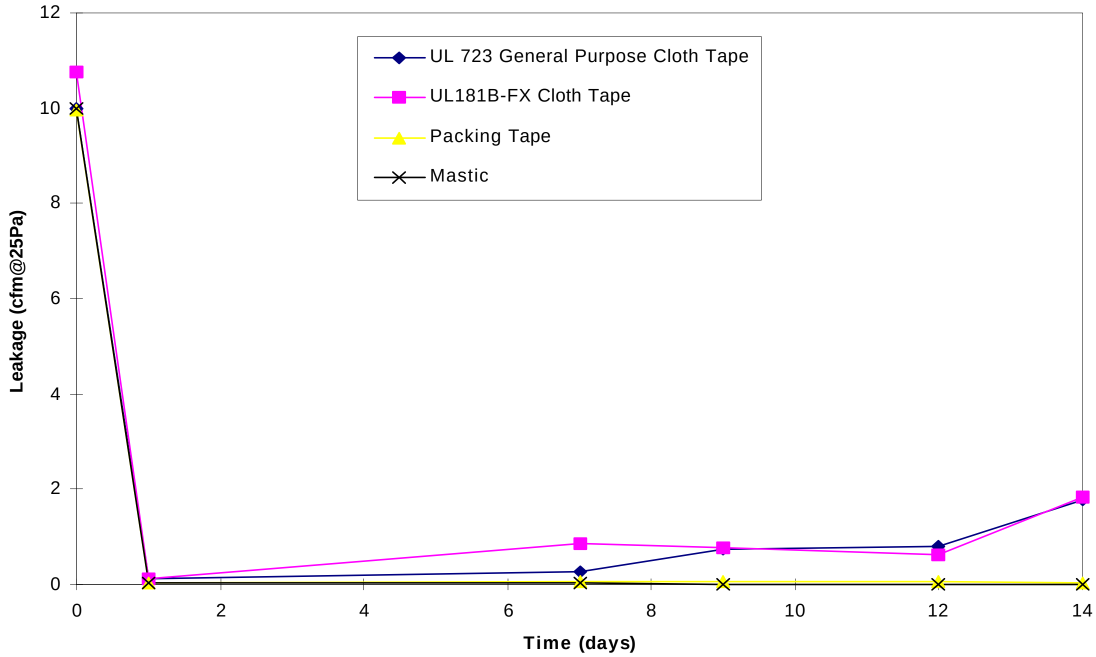
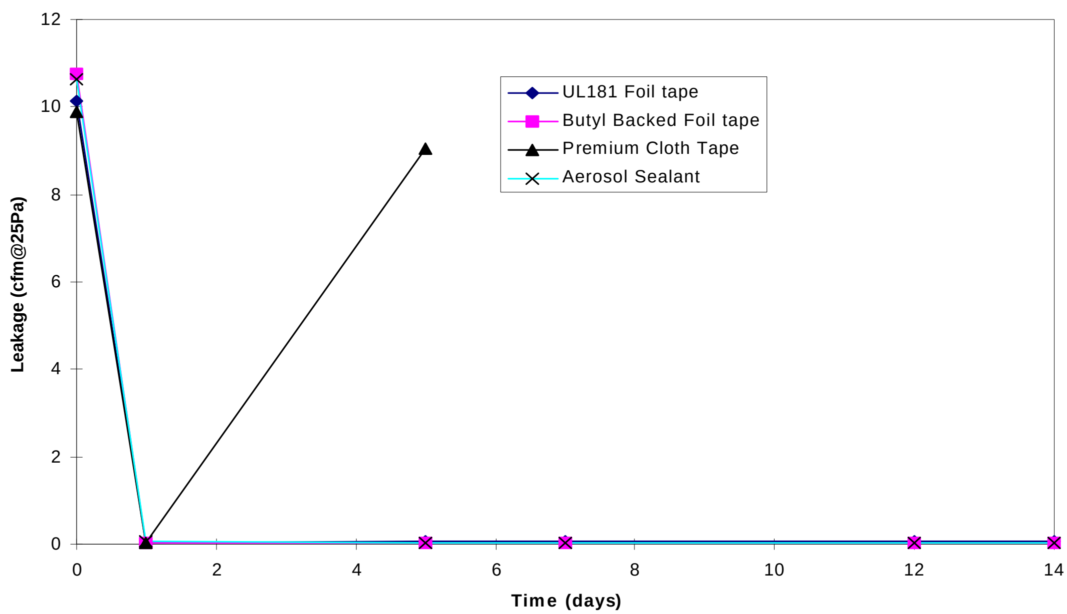


Figure 7. Changing test sample leakage from aging apparatus
a) top; b) bottom



What Did We Measure?

We have measured about 40 different samples in our three test apparatuses. Some of the samples have failed and some samples continue to be tested. Failure was determined either from visible catastrophic failure (e.g., the tape falls right off) or by a measurement that showed that the leakage was above 10% of the unsealed value.

At the conclusion of our first round of testing, the only samples that have failed are cloth duct tape. Table 2 summarizes the 18 failed duct tape samples:

TABLE 2: SUMMARY OF DUCT TAPE FAILURES:

# of Tests	***Test Type***	***Description***	***Typical Failure Time***	***Typical Leakage***
8	Aging	5 different grades	7 days	42%
5	Aging	181B-FX	10 days	18%
4	Baking	3 different grades	34 days	16%
1	Baking	181B-FX	60 days	30%

We have separated out those samples bearing the UL 181B-FX rating. Most of the duct tape samples failed within in a week in the aging test. One UL rated and one non-UL rated sample held out for over a month. Because the baking test does not stress the samples with either low temperatures, or more importantly pressure, time to failure is longer than for the aging test.

The table below summarizes all of our other measurements: There are over 20 samples that did not fail as of the conclusion of our testing; all product categories and all test methods are included. Table 3 summarizes their status:

TABLE 3: SUMMARY OF ON-GOING LONGEVITY TESTING:

# of Tests	***Test Type***	***Description***	***Duration***	***Comment***
1	Aging	**Butyl Tape**	3 months	15mm; Foil Backed
1	Aging	**Aerosol**	3 months	
1	Aging	**Mastic**	3 months	181A
1	Aging	**Foil Tape**	3 months	181A-P only
1	Aging	**Foil Tape**	1 month	181A-P & 181B
1	Aging	**Packing Tape**	3 months	
1	Aging	**Packing Tape**	1 month	181A & 181B
1	Baking	**Packing Tape**	4 months	181
1	Baking	**Aerosol**	4 months	
2	Baking	**Duct Tape**	4 months	"Premium"
3	Baking	**Duct Tape**	4 months	181B-FX
1	Baking	**Foil Tape**	4 months	181A-P
4	P Cycling	**Aerosol**	2 years	Pressure only
4	T,P Cycling	**Aerosol**	2 years	Heat and Pressure

Although virtually all of the cloth duct tape samples from the aging test have failed. Some of the cloth duct tape samples from the baking tests have not. A visual inspection of these baked samples reveals that most of the duct tape samples have delaminated and the heat has seemingly caused the rubber adhesive to harden when at room temperature. It appears that some of the samples have hardened in such a way as to maintain their seal rather like a mastic material. Because this process has happened without any pressure being applied, it is unlikely to happen similarly in the field.

There appears to be little difference in performance of the various cloth duct tapes. Different grade cloth duct tapes have clearly different properties, but most of them appear to relate to the strength of the tape rather than its longevity.

What Does It All Mean?

Duct Tape Cannot Take The Heat

Although our testing has not been able to differentiate amongst other sealant products, the data shows that cloth duct tape is not a good sealant for use in ducts that operate at much above ambient temperature. We believe this is due to the rubber adhesive, but cannot state so definitively.

For the most part, cloth backing and rubber adhesives go hand in hand. Thus it is not surprising that the other sealant products have not demonstrated any of the failure modes we have seen in the duct tapes. There are a few products that use rubber adhesives with non-cloth backing and we intend to test these in the future.

Flimsy Is Fine

Tapes with low tensile strength have done fine our testing. Because the purpose of a duct sealant is *only* to reduce leakage, strength was not a component in our testing. Some field users dislike using such tapes because of their poor strength, but proper installation of duct systems (to meet code requirements and manufacturers specifications) requires that mechanical support be provided by other means. Duct sealants are not supposed to provide it, and are not allowed to by code.

Clear, unreinforced, packing tape is used for factory built (i.e. UL 181) systems, and has been found by our testing to hold up well. At least one modified version of it has been UL 181B-FX rated and is commercially available. While we do not yet have a lot of data on this newer version, it appears to be the same and we do not expect it to perform significantly differently from the packing tapes we have been testing.

Similarly, there are now foil tape products commercially available with 181B-FX rating and we expect them to perform satisfactorily as well.

UL Ratings Do Not Address Sealant Longevity.

It may be surprising to note that there is no correlation between sealant longevity and rating with the UL test method. On closer inspection it may not such a surprising result. Many of the components of the UL testing address fire safety and strength issues and neither of these figure into our testing. We expect, in fact, that some of the sealants that appear to work well from a sealant longevity perspective (e.g. Butyl tape) may have difficulty passing UL 181B as it currently stands.

Installation Issues Are Important

Our testing focussed on the properties of the sealants themselves. We therefore spent some effort at making sure that we got good initial seals for our test section by following good practice and manufacturers instructions carefully. We made sure that, for example, the test section was clean and dry. We were meticulous in the application of the sealant and we checked for a good seal before beginning any of the tests.

In a normal application, it is not practical to take this level of care during the installation of the duct system. Access to the ducts may be limited; also, ducts may be or become dirty before the sealant is applied. Because tapes are particularly sensitive to these issues, some tape jobs may not perform well because of their installation rather than any intrinsic fault of the tape itself. Non-tape sealants can often be more tolerant of dirt and/or able to reach all the leaks.

The choice of duct sealant will vary by climate, construction type, and local experience. We would recommend that installation issues be considered, but that Anything But Duct-tape can be used as the sealant. From the sealant longevity perspective, we would not give UL-rated tapes any preference, but other issues or local codes may make UL-rated tapes desirable.

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